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Innovative Techniques to Predict Atmospheric Effects on Sensor Performance

Anthony V. Dentamaro
Patricia H. Doherty

Boston College
Institute for Scientific Ressearch
Chestnut Hill, MA 02467

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AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
29 Randolph Road
AIR FORCE MATERIEL COMMAND
Hanscom AFB, MA 01731-3010

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This technical report has been reviewed and is approved for publication.

James J. Gibson
James J. Gibson
Contract Manager

Domenic F. Thompson
Domenic F. Thompson, Maj, USAF, Chief
Battlespace Surveillance Innovation Center

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6. AUTHOR(S)

Dentamaro, Anthony V. and Doherty, Patricia H.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Boston College
Institute for Scientific Research
140 Commonwealth Avenue
Chestnut Hill, MA 02467-3862

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14. ABSTRACT

The Boston College Institute for Scientific Research (ISR) is conducting innovative research in areas relating to development and demonstration of new technologies to predict atmospheric effects on sensor performance for acquisition, mission planning and employment of the Air Force's current and next generation electro-optical (EO) systems. Emphasis includes space-, air-, and ground-based EO systems, laser systems including the Airborne Laser (ABL), surveillance and lidar and radar remote sensing technologies.

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Turbulence; Forecast and Modeling; Cloud Description and Forecasting; Space Objects Surveillance; Hyperspectral Imaging; Space Situational Awareness

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1. INTRODUCTION

During the period September 2007 through September 2008, we conducted innovative research in areas relating to the development and demonstration of new technologies to predict atmospheric effects on sensor performance for acquisition, mission planning and employment of the Air Force's current and next generation electro-optical (EO) systems. Emphasis included space-, air-, and ground-based EO systems, laser systems including the Airborne Laser (ABL), surveillance, and lidar and radar remote sensing technologies.

The work summarized above resulted in numerous presentations, technology-related conferences attended and coordination with technology related organizations and listed as follows.

1) "Exoatmospheric Plume Data and Analysis", September 2007
2) "Non-Resolved Space Object Identification for Rapid Determination of Situational Changes", September 2007
3) "Non- Resolved SOI Analysis of Spacecraft Maneuvering and Orientation – A Status Report", April 2008
4) "Spacecraft Maneuver and Motion Detection Analysis Based on Optical Measurements and Simulations", April 2008
5) "Space Object Characterization with 16-Visible-Band Measurements at Magdalena Ridge Observatory", Advanced Maui Optical and Space Surveillance Technologies Conference, September 2008

2. TURBULENCE EFFORTS

Boston College researchers, in support of the Turbulence Effort, coordinated with Space and Missile Systems Center (SMC) to fund work supporting the transfer of National Polar-Orbiting Operational Environmental Satellite System (NPOESS) ingest capability to a new Air Force Weather Agency (AFWA) facilities. The effort was combined into a larger effort and is now funded.

2.1. FY07 Forecasting and Modeling Program

Tracking and reporting of the status of the FY07 Forecasting and Modeling Program funds was continued. A mid-term review of FY07 NASA efforts under the Forecasting and Modeling Program was attended. Briefings were held outlining the progress of NASA on FY07 research funded by the Forecasting and Modeling program (currently executed by the Air Force Research Laboratory (AFRL) with Boston College Institute for Scientific Research (BC/ISR) support). They covered tasks are outlined in the following Statements of Work:

a) AFWA Snow Depth Model Algorithm Enhancements & NPOESS Preparation
b) Land Information System (LIS) Assimilation Enhancements

2.2. Delivery of NASA Land Information System (LIS)

Final delivery of NASA Land Information System (LIS) FY07 projects was August 2008. Transfer of the Weather Forecasting and Modeling Program from AFRL/RVBY to AFRL/RISA was accomplished, which provided background information and continuity as needed. Funding for the FY08 NASA Land Information System (LIS) development tasks in support of Air Force Weather was coordinated, and a Statement of Work for coupling LIS and Weather Research and Forecast (WRF) was reviewed.

2.3. Coordination with AER on Cloud Optical Properties (COP)

Boston College coordinated with Atmospheric and Environmental Research, Inc. (AER) regarding FY08 research on cloud optical properties (COP). Funding for this effort has now been put on contract. A "kick-off" meeting with AFWA, AFRL, and AER was attended to ensure that all parties understood FY08 COP requirements. This work will allow exploit use of current and planned (NPOESS) satellite data to determine the physical properties of clouds and use this information in weather analysis and forecast products. Work on determining cloud properties will continue in FY08 along with efforts to use data in support of the LIS and the Cloud Depiction and Forecasting System II (CDFSII). This work is still in coordination due to a need to re-accomplish its associated Determination and Findings (D&F). A portion of the work will be accomplished under the current D&F and a portion will be tasked under a new 5 year plan.

2.4. Coordination with NCAR and UCAR in Support of Air Force Weather

Coordination was established with the National Center for Atmospheric Research (NCAR) and the University Corporation for Atmospheric Research (UCAR) to help them prepare proposals for work in support of Air Force Weather. The FY07 NCAR final out-brief of FY07 tasks in support of Air Force Weather was attended. Also, the FY08 Statement of Work for Weather Research and Forecasting (WRF) Model Improvement and Support was reviewed. NCAR briefed tasks outlined in the following Statements of Work:

a) WRF Model Improvement and Support
b) WRF Data Assimilation Improvement and Support
c) WRF Development Test-Bed Center Support
d) Ensemble Forecasting and Development

2.5. Preparation of Determination and Findings

Boston College assisted in the preparation of a Determination and Findings Document allowing continued development of LIS by NASA using DoD funds. All tasks are currently on target to be completed by the end of the period of performance, however, there is some risk to the Data Assimilation Project due to NCAR manning issues. NCAR is working to address these issues and is hopeful that all FY08 (and remaining FY07) tasks will be completed on time.

2.6. Reviewed and Commented on Statement of Work for Support to Air Force Weather

Boston College reviewed and commented on the FY08 Statement of Work for support to Air Force Weather Agency by the UCAR Visiting Scientist Program. Scientists hired under this program perform a variety of tasks/studies in support of weather modeling at the Air Force Weather Agency. Boston College worked with the National Science Foundation to expedite funding of all FY08 UCAR projects.

2.7. Co-Chairing of the BACIMO Conference

Boston College was involved in the co-chairing of the Battlespace Atmospherics and Cloud Impacts on Military Operations (BACIMO) Conference. The objective of the BACIMO Conference was to enhance cooperation and coordination in all aspects of atmospheric, weather and cloud impacts on military operations among US military services, the civilian community, and other nations. This year's conference was hosted by Boston College. Attendees included research scientists from, DoD/Government agencies, academia, and several NATO nations. Sessions were held on:

1. Electro-Magnetic/Electro-Optic/Acoustic Models and Tools (Chaired by Mr. Wayne Patterson, Space and Naval Warfare Systems Center (SPAWAR)

2. Data Assimilation and Numerical Modeling (Chaired by Dr. Dale Barker, NCAR)

3. Characterization and Modeling of Atmospheric Processes (Chaired by Mr. John Eylander, AFWA)

4. Forecast Verification and Impacts on Military Operations (Chaired by Dr. Tom Murphree, Naval Postgraduate School (NPS))

5. Chemical/Biological/Radiological Transport and Diffusion Modeling and Assessment (Chaired by Dr Dennis Garvey, Army Research Laboratory (ARL))

6. Climatology and Additional Topic(s) of Interest (Chaired by Mr. Don Norquist, AFRL)

This work will allow exploit use of current and planned (NPOESS) satellite data to determine the physical properties of clouds and use this information in weather analysis and forecast products.

2.8. Coordination of Funding for NAVAIR Effort

Boston College researchers helped coordinate the funding of effort by Naval Air Systems Command (NAVAIR) to expand the types of weather data available to the modeling and simulation community to include live weather data. Coordination of funding was also provided for the following:

a) AFWA's FY08 Visiting Scientist Program
b) An effort by the National Geophysical Data Center to begin integration of space data into the Environmental Data Cube Support System.
c) An Army Research Laboratory effort to transition technology developed by the Army to Air Force Weather. These efforts include the development/transition of web-enabled decision aides, a weather routing tool, and a micro-scale wind model.
d) An effort to determine the feasibility of starting a Space Weather Development Test Center at NCAR.

2.9. Program Reviews Attended/Program Involvement

a. Program Reviews

1) A mid-term review for FY08 AER tasks under the Air Force Weather Agency (AFWA) Forecasting and Modeling Program. These tasks utilize a 1DVAR method of assimilating satellite data into cloud analyses. Work is proceeding on schedule and should be complete by the end of the period of performance. Copies of the mid-term review are available.
2) An Air Force Weather Program Requirements Review. Review outlines Air Force Weather Requirements for all programs (including F&M) through 2015.
3) The NASA FY07 task delivery and the NASA FY08 task mid-term review for work undertaken under the Forecasting and Modeling Program (currently executed by AFRL with BC/ISR support). The FY07 deliveries included work performed by NASA on the use of satellite data to determine the extent and depth of snow (as well as better understanding snowmelt). It also included the FY07 improvements to the Land Information System model requested by AFWA. Code was delivered and FY07 work will be considered complete following AFWA testing. Results of the FY07 work were mixed with some methods showing greater promise than others. AFWA will continue to look at how to integrate new and current methods of data assimilation to ensure best exploitation of all data. The mid-term review of FY08 LIS tasks (centered on the integration of the Community Radiative Transfer Model into LIS) was conducted. This work is slightly behind schedule due to NASA personnel issues. NASA has agreed to let all interested parties know as soon as possible if a POP adjustment will be needed.

b. Program Involvement

1) Researching answers to contracting questions for interagency agreements with NOAA.
2) Reviewing and providing input to the Forecasting and Modeling Program Section of the Office of the Federal Coordinator for Meteorology annual report.
3) Helping to facilitate the acceptance of funds by NOAA for work on WRF/Chem and the inclusion of space weather in the Environmental Data Cube.

3. SPACE OBJECTS SURVEILLANCE TECHNOLOGIES (SOST)

Boston College researchers have been involved with helping to compile and make available the large amount of satellite data taken in September at the Magdalena Ridge Observatory (MRO). A 16-band visible spectral imager, built by Solid State Scientific Corporation (SSSC), was mounted to the 2.4-m MRO telescope for eight days, and images of 40 resident space objects (RSO) were captured. In addition to the RSO's, images of 18 known calibration stars were also captured. Nearly one terabyte of raw data was processed and delivered for dissemination to the members of the SOST group. Calibration was accomplished obtaining the spectral intensity of ten of the stars and comparing the in-band intensities to the data. These ten stars provided coverage for all but one of the nights of data-taking.

3.1. Light Curves

Light curves were generated for various space objects in the different spectral bands used in the experiment. Several partially resolved objects were imaged in the data, which aided in the modeling and simulation. In particular, a resolved image of a tumbling Zenit 2M rocket body provided much information about what various features in the light curves indicated. Understanding the light curves for naturally tumbling bodies aids in the characterization of all resident space objects (RSO).

3.2. MRO Data and Optical Signatures Code (OSC)

The MRO data provided valuable tests for the modeling and simulation effort in SOST. The Optical Signatures Code (OSC) provides simulation of the motion of an RSO and generates simulated light curves depending on the Two-Line Element (TLE), satellite specifications and knowledge of satellite materials. One matter depicted out by the comparison of the experimental light curves to the OSC-generated ones is an uncertainty in the orientation of the images in the data. The fact that certain features in the Zenit light curve could not be reproduced was the first indication that the images were either rotated or mirror-reflected. Images of two pairs of double stars seem to indicate that there was a 90-degree rotation in the images. This was also seemingly borne-out by analysis of the International Space Station (ISS) data.

3.3. Materials Identification and Space Object Identification (SOI)

Materials identification and space object identification (SOI) from observation of resolved and unresolved RSO's is of great interest. The materials identification, at least to start, must actually originate from resolved object data. The best resolved image that was collected was for the ISS. In these images, one is able to choose different surfaces to analyze; e.g., a section from one of the solar panels, one section of one of the trusses and a surface on the Zarya module. These three surfaces conceivably represent different materials; coverglass, aluminum and Teflon, respectively. Observing these surfaces in the 16 spectral bands of the MRO data provides information about the materials, the objective being to use the combination of bands that gives the best differentiation between materials. This, in turn, can be used to differentiate between classes of satellites.

3.4. Process of Materials Identification Extended to Unresolved Objects

This process of materials identification can be extended to unresolved objects. Software that allows the automation of OSC runs so that thousands of sample points can be efficiently generated. In addition, several computers were rebuilt in order to accommodate multiple versions of this code in order to speed up the analysis. Simulations and calculation of spectral differences were generated for several satellites observed in the MRO data. Every possible combination of signals from any two bands (after calibration) was taken in order to find the combination of bands which best differentiates one material from another. The loci of theses spectral-difference signal points are mapped into 2-D plots which separate the materials in "feature space." By using, for example, the solar phase angle for each data point as a third parameter, the plots can be mapped into 3 dimensions, further separating the "clouds" of points.

What was done in the analysis was an a posteriori examination of RSO's; that is, using signatures from data from known satellites to reverse engineer simulation of the spectral signatures. This work will lead to the archiving of spectral plots which can be compared to signatures from unknown satellites in order to identify them. The next step, which has already been started, is to generalize the models, not to specific satellites, but to classes of satellites based on known satellite bus types in order to first classify the unknown RSO, and then identify it.

3.5. Time-Domain Analysis Simulation for Advanced Tracking (TASAT) Software

Optical Signatures Code is not the only such model that is used in SOI. The software known as Time-Domain Analysis Simulation for Advanced Tracking (TASAT) provides the user with greater ability to define the EO platform (cameras, optics, etc.) with which RSO's are observed. A copy of this software was made temporarily available and work has begun to compare it to OSC. TASAT tends to be less flexible than OSC in that one does not have the ability to construct the RSO that is to be used, but instead must pick and choose from a database of about 50 satellite models. Defining general classes or individual objects for study is all but impossible unless one has access to the software that generates the models included in TASAT. Also, a database of observation points (primarily, Starfire Optical Range and AMOS in Maui) is available but, in order to change locale, the procedure is, at least at first, tedious. Preliminary analysis of TASAT versus OSC involved simulating the flight of a flat plate in orbit and comparing the results. Assuming a Lambertian surface for simplicity, and approximately matching the plate attitude in both models, a comparison was achieved. The results matched to within a factor of about two, given the differences in the material databases and the approximate matching of orientation of the plate in both models.

3.6. Collaboration with AFRL/RYHI Hanscom AFB

Boston College research also included collaboration with AFRL/RYHI to get a sensor mounted on the test bed telescope assembly on the roof of Building 1105B for the purpose of characterizing RSO's. A new GPS time provider was procured and used in the setup. In addition, this entailed the acquisition and initial integration of an internal PCI card GPS time standard to help eliminate temporal causes of satellite tracking jitter. Another major accomplishment has been the delivery of a grating and its subsequent mounting on the 14" Celestron telescope on the roof. The grating generates the zeroth-order image and the first-order visible spectrum of its target. In the initial test, images were taken of several bright stars for which the spectrum is well-known. Digitizing the collected spectrum yields a calibration when compared to the archived spectra.

In addition, installation of the Sensors Cross Dispersion Prism on the Paramount mount in the telescope dome on the roof of Building 1105B was finalized, and initial measurements have been made. Data was taken on several stars and planets, mostly during early morning hours. The experiment was valuable in setting a baseline for the operation of this instrument in tracking mode.

4. HYPERSPECTRAL IMAGING (HSI)

Boston College researchers have also been involved with three projects in AFRL/RVBYH: the TacSat-3 program, the image processing software FLAASH, and the radiation transport equation solver MODTRAN™.

4.1. TacSat-3 Program

The TacSat-3 program is producing a satellite-based hyperspectral sensor scheduled to fly in 2008, and BC is writing most of the software to package image data downloaded from the satellite. The bulk of the software has been written, and the present work is focusing on integrating the software with other software written by government and contractor sources to provide a complete processing chain. This is an automated system that ingests raw data from the satellite, processes it through many steps, and generates images and metadata suitable for analysis by scientists.

4.2. FLAASH Code Image Processing Software

The FLAASH code is image processing software designed to remove the effects of the atmosphere from airborne or satellite imagery. Boston College has been responsible for improvements in this code related to the processing of very large images. These images are so large that different atmospheric characteristics separated by the large distances bounded by the image can affect the accuracy of the results. Previously, FLAASH allowed only a single atmospheric description for an image, but the modifications performed allow multiple definitions which improve results for these large images.

4.3. MODTRAN™

The effort related to MODTRAN™, a computer program to calculate radiation transport equations, has been verification and validation of a new version of the legacy system. MODTRAN™ is a very old code, written in Fortran, but has been modified over the years to follow the current state of the art in radiation transport theory. The software coding practices have not been modernized, however, and this results in a large effort to verify the output of the code. Boston College has been pushing for modernization of the coding standards as a means of improving the testability of the code.

5. SPACE SITUATIONAL AWARENESS (SSA)

Collaboration continued with Advanced Missile Signature Center (AMSC) on exoatmospheric plume phenomenology for space target applications. Development of sensing and identification algorithms for low-thrust level plumes along with decision architectures that incorporate fused and integrated components of the space surveillance network continued, as well as activity in hardbody orientation observables exploitation by investigating spacecraft solar glint signature observables and low thrust engine firings. Boston College supported AFRL/RV in the development of a concept plan and with agendas for both classified and unclassified sections of a space engine plume workshop. Boston College also supported AFRL/DE in its astronomical sensing and astrodynamics disciplines as part of the space object maneuvering detection program. Support in developing an integrated plan summary for SBIR products was also established.

6. Conclusions

Over the period September 2007 to September 2008, Boston College has supported Air Force in general and AFRL efforts in particular in the primary areas of turbulence, space object identification and characterization, space situational awareness and hyperspectral imaging.

In the Turbulence effort, Boston College was involved in the tracking and reporting of status for the Forecasting and Modeling Program, as well as the final delivery of NASA land information system projects. Boston College coordinated with AER on cloud optical properties research and with NCAR and UCAR in support of Air Force weather research. There was coordination of funding for AFWA for the Visiting Scientist Program, with ARL for technology transition between the Army and Air Force, with NCAR for the development of a Space Weather Development Test Center and with NAVAIR to expand the types of weather data available to the modeling and simulation community. There were program reviews for the Air Force Weather Program, for NASA for tasks undertaken under the Forecasting and Modeling Program and for AER tasks under the auspices of AFWA. Finally, under the Turbulence effort, Boston College was involved in the co-chairing of the BACIMO conference.

In the Space Objects Surveillance Technologies effort, extensive analysis of images of resident space objects taken with a 16-band multilens imager mounted to the 2.4-m telescope at the Magdalena Ridge Observatory was undertaken. Light curves generated from this data were used to develop Modeling and Simulation techniques to aid in the identification and characterization of satellites. Resolved images of the International Space Station led to an analysis of space materials properties which provides an additional tool for space object identification. Experimentally, the start-up Satellite Tracking effort at AFRL was supported by Boston College. Instead of depending on and supporting other facilities for data on low-Earth orbit objects, AFRL hopes to eventually collect their own multispectral and polarization data for satellite light curves.

Boston College also continued to support the Hyperspectral Imaging effort at AFRL by writing software to package image data downloaded from the TacSat-3 satellite and improving the FLAASH code used for image processing. Validation and verification of a new version of the MODTRAN™ radiation transport code has also been addressed.

In the area of Space Situational Awareness, Boston College collaborated with AMSC on exoatmospheric plume phenomenology for space target applications and continued its work in the development of sensing and identification algorithms for low-thrust level plumes.

7. List of Symbols, Abbreviations, and Acronyms

ABL	Airborne Laser
AER	Atmospheric and Environmental Research, Inc.
AFRL	Air Force Research Laboratory
AFWA	Air Force Weather Agency
AMOS	Air Force Maui Optical Station
AMSC	Advanced Missile Signature Center
BACIMO	Battlespace Atmospherics and Cloud Impacts on Military Operations
BC/ISR	Boston College/Institute of Scientific Research
CDFSII	Cloud Depiction and Forecasting System II
COP	Cloud Optical Properties
D&F	Determination and Findings
DoD	Department of Defense
EO	Electro-Optical
F&M	Forecasting and Modeling
FLAASH	Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes
GPS	Global Positioning System
HSI	Hyperspectral Imaging
ISS	International Space Station
LIS	Land Information System
MODTRAN™	Moderate Resolution Atmospheric Transmission
MRO	Magdalena Ridge Observatory
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVAIR	Naval Air Systems Command
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPS	Naval Postgraduate School
OSC	Optical Signatures Code
POP	Proof Of Principle
RSO	Resident Space Object
RYHI	IR Sensors Technology Branch
SBIR	Small Business Innovation Research
SMC	Space and Missile Systems Center
SOI	Space Object Identification
SOST	Space Objects Surveillance Technologies
SPAWAR	Space and Naval Warfare Systems Center
SSA	Space Situational Awareness
SSSC	Solid State Scientific Corporation
TASAT	Time-Domain Analysis Simulation for Advanced Tracking
TLE	Two-Line Element
UCAR	University Corporation for Atmospheric Research
WRF	Weather Research and Forecast